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# A study of the effects of added solid-liquid interfacial area on the stabilization characteristics of simulated wastewater stabilization lagoons

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# A STUDY OF THE EFFECTS OF ADDED SOLID-LIQUID INTERFACIAL AREA ON THE STABILIZATION CHARACTERISTICS OF SIMULATED WASTEWATER STABILIZATION LAGOONS

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# ABSTRACT

Wastewater stabilization lagoons have recently become a popular and efficient method of sewage stabilization in many parts of the country. The purpose of this investigation was to determine the effect of added solid-liquid interfacial area on the treatment capabilities of simulated wastewater stabilization lagoons.

The simulated lagoons consisted of six-15 gallon aquariums which were operated in the laboratory. The solid-liquid interfacial area was increased in four of these lagoons by suspending plastic panels in the aquariums. The lagoons were operated for a period of approximately two and a half months using dehydrated milk as a simulated waste substrate. During this period various analyses were conducted periodically on the effluent from each lagoon. The most significant of these tests were COD, suspended solids, dissolved oxygen, and pH.

The principle conclusion based on this investigation was that added solid-liquid interfacial area has little effect on the treatment capabilities of laboratory lagoons. However, this modification in lagoon treatment may have some merit if applied to field scale lagoons. Further research is needed to fully explore the possible benefit of this modification in the lagoon treatment process.

# ACKNOWLEDGEMENTS

The author would like to express his sincere appreciation to Dr. Ralph H. Clark for suggesting this interesting research topic, and for his guidance and encouragement while the work was being done.

The author would also like to thank his wife, Darlene, whose typing abilities along with her patience and understanding made this work a lot easier.

# TABLE OF CONTENTS

Table of Contents (continued) Page

# LIST OF ILLUSTRATIONS

Figures Page

# LIST OF TABLES

# I. INTRODUCTION

One wastewater stabilization process which has gained wide acceptance in this country recently is the wastewater stabilization lagoon. The wastewater stabilization lagoon is a biological treatment process which greatly resembles the waste stabilization carried on in a stream or natural body of water. The lagoon itself is a man-made body of water of specific dimensions, into which waste products are discharged. The waste products are retained in the lagoon until biological action has stabilized them to such an extent that they may be safely discharged into a natural body of water.

Wastewater stabilization ponds have gained wide acceptance as domestic waste treatment facilities because of their simplicity, efficiency, and low cost. A stabilization lagoon does not require highly skilled personnel for operation and maintenance. Once the lagoon has been built and filled, and the symbiotic biological process has begun to take place, the lagoon requires little attention and a relatively high degree of waste stabilization may be achieved. The primary advantage of a stabilization lagoon, as compared with other treatment processes, is the low cost. Where the price of land is not too high, such as in rural areas, lagoons are a particularly suitable means of wastewater treatment. Since the stabilization pond does require more area for a given population than most other treatment processes, land value is of critical importance in its overall cost.

There are certain operational problems associated with the use of lagoons such as odor control, pest control, and sludge buildup on the lagoon bottom. The solution of these problems is relatively simple using sound operating procedures. There are other problems associated with the use of stabilization ponds that cannot be solved so simply. Two of these problems include the large amount of land area required, and the discharge of algal solids into receiving bodies of water by lagoons. It is primarily these two problems which inspired this investigation.

The size of a wastewater stabilization lagoon is determined primarily by the amount of organic loading placed on it. Accepted design criteria specify the amount of organic loading which may be applied per unit area of a lagoon. A typical loading for this area would be 45 pounds of biochemical oxygen demand (BOD) per acre per day (1). These design criteria are necessary if the lagoon is to obtain satisfactory stabilization of the organic load placed on it. If it were possible to increase the loading rate placed on a stabilization pond and still obtain satisfactory stabilization, the required size of the pond could be decreased. This would decrease its cost, since less land area would be required.

To obtain satisfactory stabilization of the organic load fed to a pond, a certain microbial mass must exist. The potential for waste stabilization in a lagoon is proportional to the microbial mass. An increase in the organic loading rate would increase the microbial

population in the lagoon. This increase in microbial population in the lagoon would be undesirable if it resulted in a decrease in the quality of the effluent, such as an increase in the discharged algal solids. A logical approach to the problem would be to find a way to increase the microbial population in the lagoon and to prevent this increased population from being flushed from the lagoon. The microbial population can be easily increased by increasing the loading rate, therefore, the problem at hand is to prevent the flushing of the increased microbial population from the lagoon.

There exist in nature many forms of microbial life which will readily, and preferably, attach to and grow on a solid surface if one is present. This is evident in a stream or lake where most submerged surfaces have a film of microbial growth attached to them at the solid-liquid interface. At this solid-liquid interface, the microbial population is much more concentrated than that in suspension. Many industrial fermentations, such as the quick vinegar process, rely on attached microorganisms. The ability of some forms of microbial life to attach to a solid surface makes possible the operation of a trickling filter, a very common method of wastewater stabilization in this country. In the trickling filter the organisms remain attached to the filter media even though an intermittent flow of sewage runs over the media.

It may be beneficial to increase the amount of solid-liquid interfacial area in a stabilization lagoon. If a microbial growth could be

established on this added solid-liquid interfacial area, this growth would not be flushed from the lagoon with increased loading rates. It may then be possible to establish a higher microbial population in the lagoon without decreasing the quality of the effluent.

To increase the amount of solid-liquid interfacial area in a stabilization pond, panels of some biologically inert material could be suspended in the pond. These "bio-growth panels" would provide a solid surface on which the organisms could attach, and would therefore increase the amount of biological solids which could grow in the lagoon. The purpose of this investigation was to evaluate the effects of such bio-growth panels on the stabilization potential of simulated wastewater stabilization lagoons.

# II. LITERATURE REVIEW

There is very little material in the literature dealing specifically with the effect of solid-liquid interfacial area on the stabilization potential of a lagoon. However, it is believed that any investigations dealing with fixed film biological growths in a waste stabilization process would be of interest. Therefore, the literature review has been divided into two sections: (a) The effect of solid-liquid interfacial area on the stabilization potential of a wastewater stabilization lagoon and (b) The use of fixed film biological growths in other wastewater stabilization processes.

## A. THE EFFECT OF SOLID-LIQUID INTERFACIAL AREA ON THE STABILIZATION POTENTIAL OF A WASTEWATER STABILIZATION LAGOON

Investigations conducted by Klock and Durham (2) indicate that winter failure due to thermal stratification and short circuiting may be eliminated by channeling and mixing the influent of a wastewater stabilization lagoon. Channeling of the influent was accomplished by the installation of a few polyethylene plastic sheets in rows at the influent end of the lagoon. Limited liquid mixing to resuspend solids and maintain surface oxygen uptake was provided by air-lift pumps. The authors attributed the benefit received from this installation to the prevention of thermal stratification and short circuiting. No mention was made of any microbial growth occurring on the plastic

sheets or the effects this would have on the treatment capabilities of the lagoon.

Investigations by Nemerow (3) on full-scale pilot plant wastewater stabilization basins indicated the achievement of greater biochemical oxygen demand (BOD) removals in closely baffled lagoons, as compared with unbaffled lagoons with similar design and operation characteristics. The investigation was carried out on five stabilization lagoons operated for a period of approximately one year. Effects of change in environment, loading, basin depth, and close-baffled construction were noted during this period. A specific conclusion resulting from this investigation stated that greater BOD removals occurred during all seasons in the baffled lagoons than in an unbaffled lagoon of the same depth at similar loadings and detention periods. There was no mention of the amount of increase in solid-liquid interfacial area present in the baffled lagoons nor biological growths occurring on the baffles. The improved treatment may have resulted partially from the increased interfacial area.

## B. THE USE OF FIXED FILM BIOLOGICAL GROWTHS IN OTHER WASTEWATER STABILIZATION PROCESSES

There are many types of wastewater treatment processes which utilize a fixed film biological growth during some phase of the stabilization process. In these types of treatment processes, a biological growth on a solid surface is responsible for at least a portion of the stabilization process. The most common among these processes is

the trickling filter. The trickling filter process relies on the biological growths which occur on the filter media to stabilize the organic components of the wastewater passed through it.

There are other types of wastewater treatment processes which utilize a fixed film biological growth, that are not as common as the trickling filter. These processes include the Rotating Biological Contactor Process (4) and the Fixed Activated Sludge Process (5). Since these treatment processes are somewhat uncommon, a brief description of their operation will be given.

The Rotating Biological Contactor Process, or Bio-Disc Process (4), is a secondary biological treatment system. It consists of closely spaced discs mounted on a horizontal shaft and rotated while partially submerged in wastewater. The biological growth which develops on the surface of the discs shortly after start-up is responsible for treatment of the wastewater. As the discs rotate, the growth is intermittently in contact with the wastewater and the wastewater is aerated. Some of the organic materials in the wastewater are either oxidized or assimilated by the growth, or stored by the growth for oxidation or synthesis at a later time. As the mass of biological growth increases, the growth begins to slough into the mixed liquor. However, the mixing action of the discs keeps the solids in suspension until the treated wastewater flows from the tank containing the discs. After leaving the tank, sedimentation removes the sloughed solids for ultimate disposal. This wastewater treatment process has a high BOD

removal capacity when treating concentrated wastes; BOD reductions of 90 per cent or more can be achieved on many industrial wastes.

The Fixed Activated Sludge Process, or, briefly, FAS Process (5), is a modification of the conventional activated sludge process. Unlike the conventional activated sludge process, the FAS process utilizes vertical plastic panels in the aeration tank. Most of the activated sludge in the aeration tank is fixed on this meshwork of plastic net panels. This makes the return of activated sludge from the settling tanks unnecessary. The primary advantage of the FAS process compared to the conventional activated sludge process is the reduction of bulking of the activated sludge. When bulking occurs it becomes difficult to make the mixed liquor separate into supernatant and flocculated sludge in the settling tank. Therefore, the bulky sludge would be carried out of the settling tank. This not only degrades the quality of the effluent, but also decreases the sludge concentration in the aeration tank. Little bulking will occur in the FAS process since the activated sludge is attached to the panels in the aeration tank.

## C. SUMMARY

It is apparent that fixed biological films will grow on a solid surface under various conditions found in wastewater treatment processes, and that these growths play an important role in the treatment. Therefore, fixed film biological growths could have an application in the lagoon type of wastewater treatment. If additional solid-liquid

interfacial area were provided on which the growth could attach, it might be possible to increase the microbial population in a stabilization lagoon. This increased microbial population may then increase the stabilization potential of the lagoon without reducing the quality of the effluent.

# III. EXPERIMENTAL PROCEDURES AND TECHNIQUE

This investigation was conducted under laboratory conditions. An attempt was made to simulate field wastewater stabilization lagoons and still maintain a somewhat controlled environment. A complete description of the laboratory setup and laboratory technique used in this investigation follows.

## A. LABORATORY SETUP

### 1. Aquariums.

Aquariums were used in this investigation to simulate the wastewater stabilization lagoons. The size of the aquariums was 60 cm long by 30.5 cm wide by 30 cm deep; each aquarium had a capacity of approximately 15 gallons. For the sake of convenience the operational liquid volume in each aquarium was 45 liters, which produced a liquid depth of 24.6 cm.

A total of six aquariums was used in this investigation. Four of these aquariums were modified in order to increase their solid-liquid interfacial area (SLIA). This increase in SLIA was accomplished by the addition of 1/16 in. Plexiglass panels to the four aquariums. The size and number of these added panels was such that the SLIA was doubled in two of the aquariums and quadrupled in the other two, as compared to the two aquariums which had no panels added. These panels were installed by cementing the ends of the panels to the sides of the aquariums with silicone caulking compound.

The two aquariums with the doubled SLIA contained five added panels. Four of these panels rested 3 cm from the bottom of the aquarium and 1 cm below the operational liquid level. The center panel rested 4 cm from the bottom of the aquarium and extended above the operational liquid level. The two aquariums with the quadrupled SLIA contained 15 added panels. Thirteen of these panels rested 3 cm above the bottom of the aquarium and 1 cm below the operational liquid level. Two panels which were at the one-third points in the aquariums rested 4 cm from the bottom of the aquarium and extended above the operational liquid level.

This panel arrangement was such that all panels contributed the same amount of SLIA. The arrangement also allowed for interaction between the different cells formed in the aquariums. The few panels which extended above the operational liquid level allowed the examination of the microbial growth which developed at the liquid line.

Table I gives a geometrical description and a relative comparison of each of the aquariums used in this investigation. Since there were two of each type of aquarium, there were two independent sets of aquariums. Each set contained one aquarium with no added SLIA, one aquarium in which the SLIA had been doubled, and one aquarium in which the SLIA had been quadrupled. The sets were designated set A and set B, and the aquariums were designated 1, 2, or 4, depending on their relative amount of SLIA. Figure 1 shows a comparison of the aquariums which make up one complete set.

Table I. A Comparison of the Aquariums.

| Aquarium | Number of panels added | SLIA contributed by panels ($cm^2$) | Total SLIA ($cm^2$) | Relative SLIA | SLIA to volume ratio ($m^2/l$) |
|---|---|---|---|---|---|
| 1-A | 0 | 0 | 6283 | 1 | 0.014 |
| 1-B | 0 | 0 | 6283 | 1 | 0.014 |
| 2-A | 5 | 6283 | 12566 | 2 | 0.028 |
| 2-B | 5 | 6283 | 12566 | 2 | 0.028 |
| 4-A | 15 | 18849 | 25132 | 4 | 0.056 |
| 4-B | 15 | 18849 | 25132 | 4 | 0.056 |

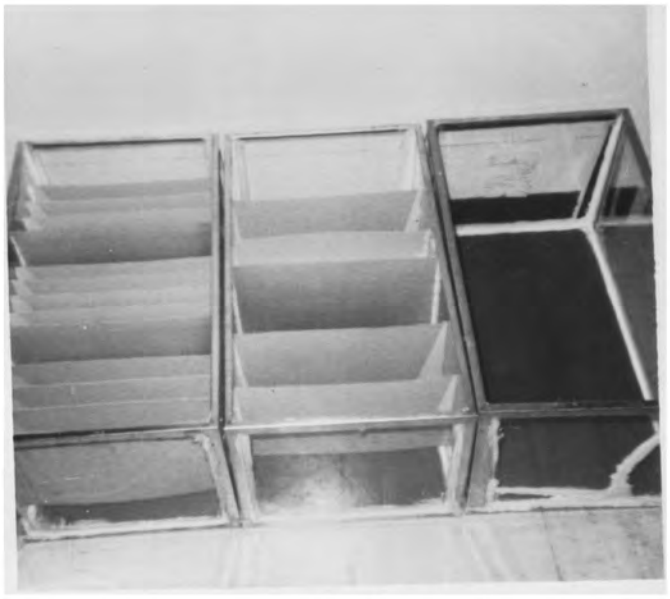


Figure 1. One Set of Aquariums.

2. Environmental Conditions.

Simulated sunlight was supplied to the aquariums by means of four General Electric F40 PL plant lights, 4 ft in length, positioned approximately 32 cm above the liquid level. Based on the manufacturer's data, this would provide a light intensity at the liquid level of approximately 600 foot candles. This intensity is within the range of light intensities which usually exists at the surface of a lagoon (6). The lights were positioned above the aquariums in such a way as to provide approximately the same amount of light to each.

The lights were turned on and off automatically by means of a timing device attached to the light bank. Each day the lights were turned on at 6:00 a.m. and off at 6:00 p.m., thus providing 12 hours of light and 12 hours of darkness to the aquariums each day. Interferences from other sources of light during the night were eliminated by lining the sides of the exposed aquariums with cardboard.

Simulated wind was supplied to the aquariums by means of a small electric fan. The fan was positioned to blow directly across the liquid surface by means of a reciprocating action. The fan was run continuously during the investigation, except during feeding and sampling periods. The air currents from the fan produced little wave action on the liquid surface of the aquariums due to the small size of the aquariums, and the blocking of the wind by panels which extended above the liquid level.

The investigation was conducted in an air conditioned laboratory,

where the room temperature remained approximately constant at 68°F. Figure 2 shows a view of the complete laboratory setup.

3. Simulated Waste Substrate.

A simulated waste substrate was used in this investigation for convenience in maintaining a known and controlled loading rate. The influent to the simulated lagoons had to be of such a nature that the strength could be held constant, or varied, without changing the influent volume. It would have been impractical to use actual domestic wastewater, since the characteristics of most domestic wastewaters change from day to day. The use of a simulated waste substrate should have little effect on the outcome of this investigation provided the simulated substrate adequately supplies the microbial requirements.

The simulated waste substrate used in this investigation was composed of non-fat, dehydrated milk (Carnation Company) dissolved in Rolla tapwater. Milk was used as the substrate because of its composition and ease of handling. Milk is a common simulated waste substrate which has been successfully used in other laboratory wastewater stabilization lagoon investigations (7).

The dehydrated, non-fat milk used in this investigation exhibited a chemical oxygen demand (COD) of 1024 mg per gram of milk. Additional information pertaining to this milk was furnished courtesy of the Carnation Company Research Laboratories (8), and is presented in Table II.

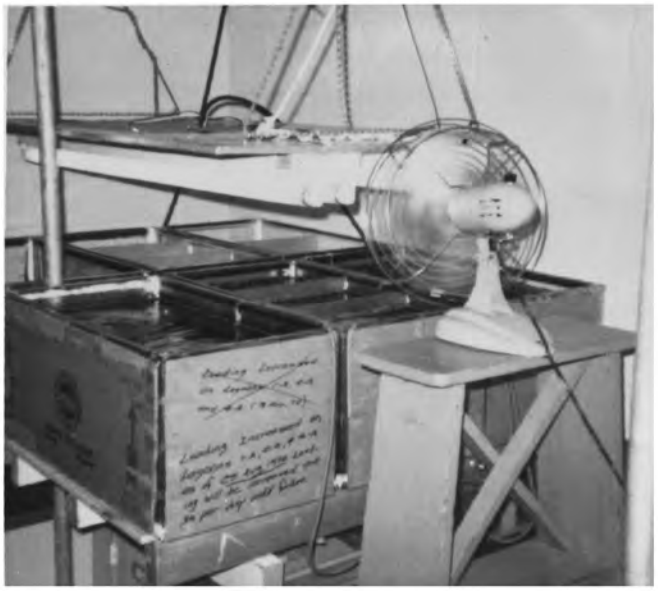


Figure 2. The Complete Laboratory Setup.

Table II. Typical Analysis of Carnation Evaporated Milk.

| | Amount/100 g |
|---|---|
| **PROXIMATE** | |
| Moisture, g | 73.7 |
| Protein, g | 7.0 |
| Fat, g | 7.9 |
| Ash, g | 1.5 |
| Carbohydrate, g | 9.9 |
| Calories | 138 |
| Nitrogen, g | 1.1 |
| **MINERALS** | |
| Calcium, g | 0.252 |
| Phosphorus, g | 0.205 |
| Potassium, g | 0.303 |
| Sodium, g | 1.118 |
| Iron, mg | 0.100 |
| Magnesium, g | 0.025 |

4. The Limitations of Simulated Lagoons.

There are many factors which make the simulation of a wastewater stabilization lagoon in the laboratory extremely difficult. These factors include geometric configurations and environmental conditions. Some of the more significant of these factors will be briefly discussed to point out the limitations of this laboratory investigation.

Size is perhaps the most significant limiting factor since it is impossible to approximate the size of a field lagoon in the laboratory. The geometric configuration of a laboratory lagoon differs greatly from that of a field lagoon. Many field lagoons operate with a liquid depth of approximately 3 feet, while laboratory lagoons usually have a liquid depth of less than 1 foot. This shallow depth could prevent the development of a significant benthal region. Since light and oxygen could penetrate a greater portion of the liquid depth, the shallow depth could also prevent the microbial stratification found in field lagoons. In a shallow laboratory lagoon, it would be possible, depending on the loading, for algae and aerobic bacteria to exist at the bottom of the lagoon, which is rarely the case in a field lagoon.

Another geometrical factor which would be very difficult to simulate in the laboratory is the SLIA to volume ratio. A small field lagoon 1 acre in area and 3 feet deep would have a SLIA to volume ratio of approximately 0.33 $ft^2/ft^3$. However, the laboratory lagoons with no added SLIA had a SLIA to volume ratio of approximately

4 $ft^2/ft^3$. To approach field conditions the laboratory lagoons would have to be extremely shallow. This would make them difficult to operate due to evaporation losses and would increase the problems already discussed concerning shallow laboratory lagoons.

Environmental conditions are also very difficult to simulate in the laboratory. Although plant lights were used to simulate sunlight, these lights had no daily or seasonal variations in intensity, as does actual sunlight reaching the surface of a field lagoon. There were little humidity and temperature variations in the laboratory, whereas field lagoons sometimes undergo wide variations in temperature and humidity. Wind action had little effect on the laboratory lagoons, since no waves were produced on the liquid surface. Wave action has both a mixing and an aeration effect on field lagoons. These differences, and the differences in substrate, would not produce the same flora in laboratory lagoons as found in field lagoons.

There are many differences between field lagoons and laboratory lagoons operating in a controlled environment. Because of these differences the results obtained from investigations on laboratory lagoons cannot be directly applied to field lagoons. However, laboratory investigations of this type are often valuable because they indicate qualitatively what might happen in a field lagoon.

## B. LABORATORY TECHNIQUE

Each of the six laboratory lagoons was initially seeded with 45 liters of a mixture of domestic wastewater and seed from two field

lagoons. Approximately half of this mixture was taken from the Love Creek Trickling Filter Plant at Rolla, subsequent to primary sedimentation. The rest of the seed mixture was taken equally from two wastewater stabilization lagoons located at the Woodcrest Trailer Park at Rolla. This mixture was used in order to provide a mixed microbial population in the simulated wastewater stabilization ponds.

1. Feeding and Mixing.

A batch feeding process was used to supply the influent to the simulated lagoons in this investigation. The lagoons were fed every day. The feeding process began at approximately 9:00 a.m. and required about one hour to feed all six lagoons. As was previously stated, the operational liquid volume in the aquariums was 45 liters. The lagoons were operated with a detention time of 15 days, therefore, the daily influent volume was 3 liters. The influent substrate was prepared 24 hours in advance and was stored in open containers at room temperature; this assured that all dehydrated milk would go into solution and all the chlorine would disappear prior to feeding.

The effluent was taken from the lagoons by means of rubber tubes attached to the sides of the aquariums. The tubes extended approximately 7 cm below the operational liquid level in the lagoons, and were positioned in such a manner that the effluent could be removed by siphoning action. The effluent tubes were attached to the inside walls of the aquariums with silicone caulking compound, and these tubes were positioned at the longitudinal midpoint of the aquariums.

After the effluent had been siphoned from the lagoons, the influent substrate was vigorously agitated and poured evenly over the liquid surface.

There were some evaporation losses from the lagoons due to the heat from the lights and the wind from the fan. Therefore, to maintain a constant operational liquid level at a specific influent rate, the volume of effluent taken from the lagoons each day was less than the 3 liter influent volume. The losses due to evaporation were small, amounting to only a fraction of a liter each day.

Initially, some difficulty was experienced in maintaining an active biological mass in the lagoons. The organisms settled out of suspension and could not come in contact with a significant portion of the influent substrate. This caused a large part of the organisms to die and the lagoons to fail. After an initial failure of the lagoons in less than a week of operation, the difficulty was overcome by gently mixing the liquid after each feeding. The mixing was done with a T-shaped stirring rod. The T-shaped rod was inverted and lowered to the bottom of the lagoon and gently rotated. This mixing would disperse the organisms and the substrate throughout the lagoon, thus allowing the organisms to come in contact with the substrate. After the mixing procedure was initiated no difficulty was experienced in maintaining an active biological mass in the lagoons.

2. Sampling.

All samples taken from the lagoons, except those used for

determining pH, were taken from the effluent siphoning tubes. Before the sample was taken, approximately 1 liter of effluent was drained from the lagoons to clear the lines of stale effluent. All effluent except that used for testing purposes was wasted. Samples were generally taken immediately prior to feeding. All samples were refrigerated and the analyses performed within 3 hours, except the dissolved oxygen concentration and pH, which were determined immediately.

Since some difficulty was encountered in establishing an active biological mass in the lagoons, the lagoons were operated for a period of approximately three weeks before all testing was started. During this time only COD tests were being conducted to evaluate the performance of the lagoons. It was felt that this length of time was necessary in order to establish a somewhat acclimatized microbial population in the lagoons. The COD tests were being run at this time simply to determine what stabilization of the influent was being accomplished in the lagoons.

All COD tests were performed on samples which had been centrifuged for approximately 5 minutes at 700 revolutions per minute (RPM). This was done to eliminate the effect of the gross microbial matter on the results of the test. All COD tests were run according to the procedures set forth in Standard Methods (9).

After approximately three weeks of operation, other tests were initiated to help evaluate the performance of the laboratory lagoons.

These tests included the potentiometric titration method for determining alkalinity, the azide modification of the iodometric method for determining dissolved oxygen content, biochemical oxygen demand (BOD), total suspended matter, and pH. All of these tests except the total suspended matter and pH tests were run according to the procedures set forth in Standard Methods (9). The total suspended matter determinations were done by filtering the sample through a glass fiber filter instead of an asbestos mat. The pH determinations were made on a Beckman Zeromatic laboratory pH meter.

# IV. EXPERIMENTAL RESULTS

Since two independent sets of lagoons were used in this investigation; the results will be graphed separately for each set. This is necessary because the loading was not always identical for each set.

Comparisons of the influent and effluent COD values for the two sets of lagoons are shown in Figures 3 and 4. Figures 5 and 6 show comparisons of the suspended solids in the effluents from both sets of lagoons, and Figures 7 and 8 show comparisons of the pH values. The numerical data from which these figures were derived is given in Appendix A.

Note from these comparisons that the results do not indicate a significant difference of operational efficiency within either set. Wide variations in the data, typical for all lagoons, are evident. This can be seen by examining the effluent COD data. After approximately 30 days of operation a sharp increase followed by a sharp decrease in effluent COD values was observed. All lagoons exhibited similar characteristics during this period. No consistent trend showing a difference in treatment capabilities was evident.

Approximately ten days after the lagoons were seeded, dissolved oxygen determinations were made. The results of these tests indicated that the dissolved oxygen content of the lagoons was zero or nearly zero. All the dissolved oxygen determinations which were run thereafter gave the same results. The dissolved oxygen content of the

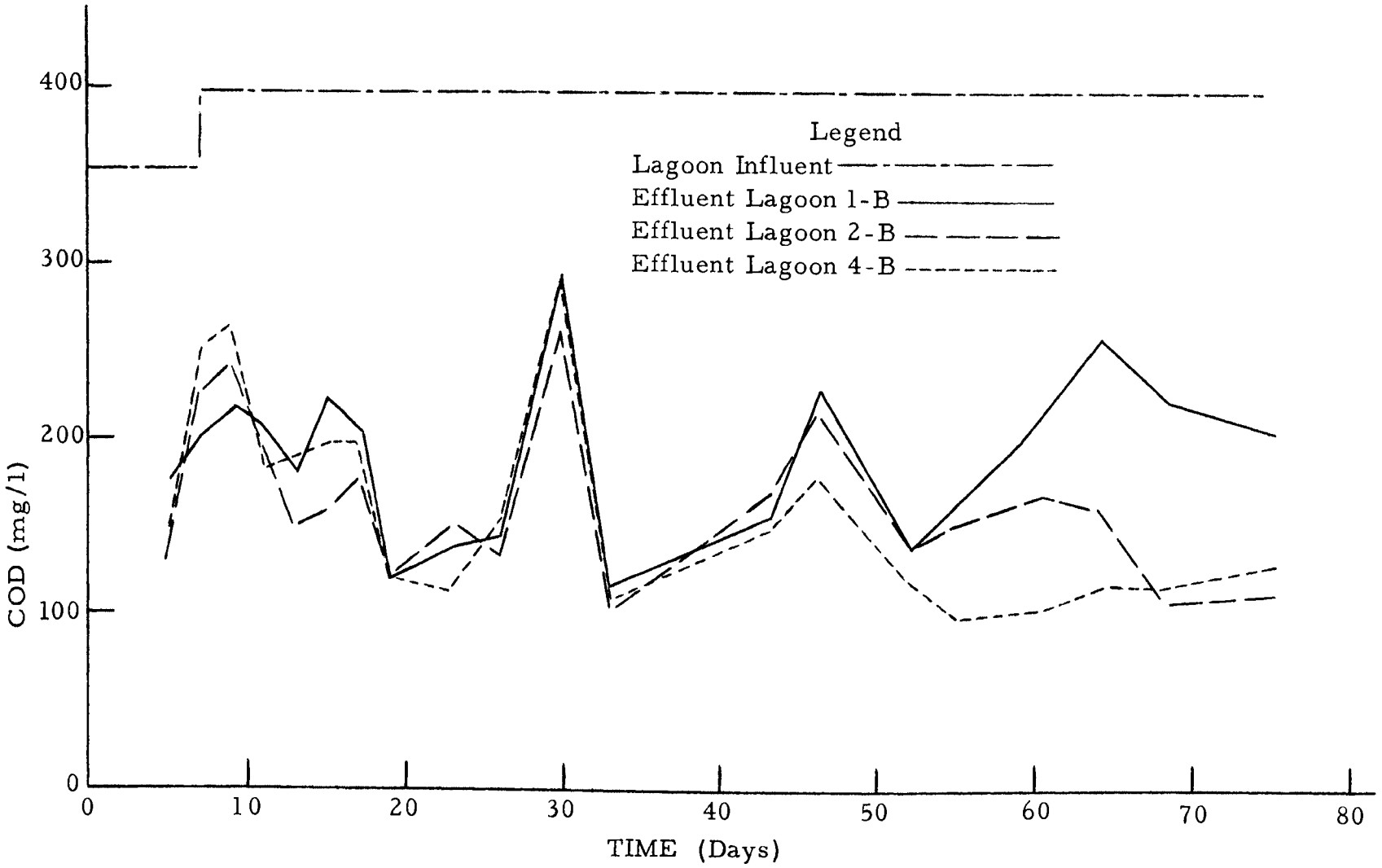


Figure 3. A Comparison of the Influent and Effluent COD of Lagoons 1-B, 2-B, and 4-B.

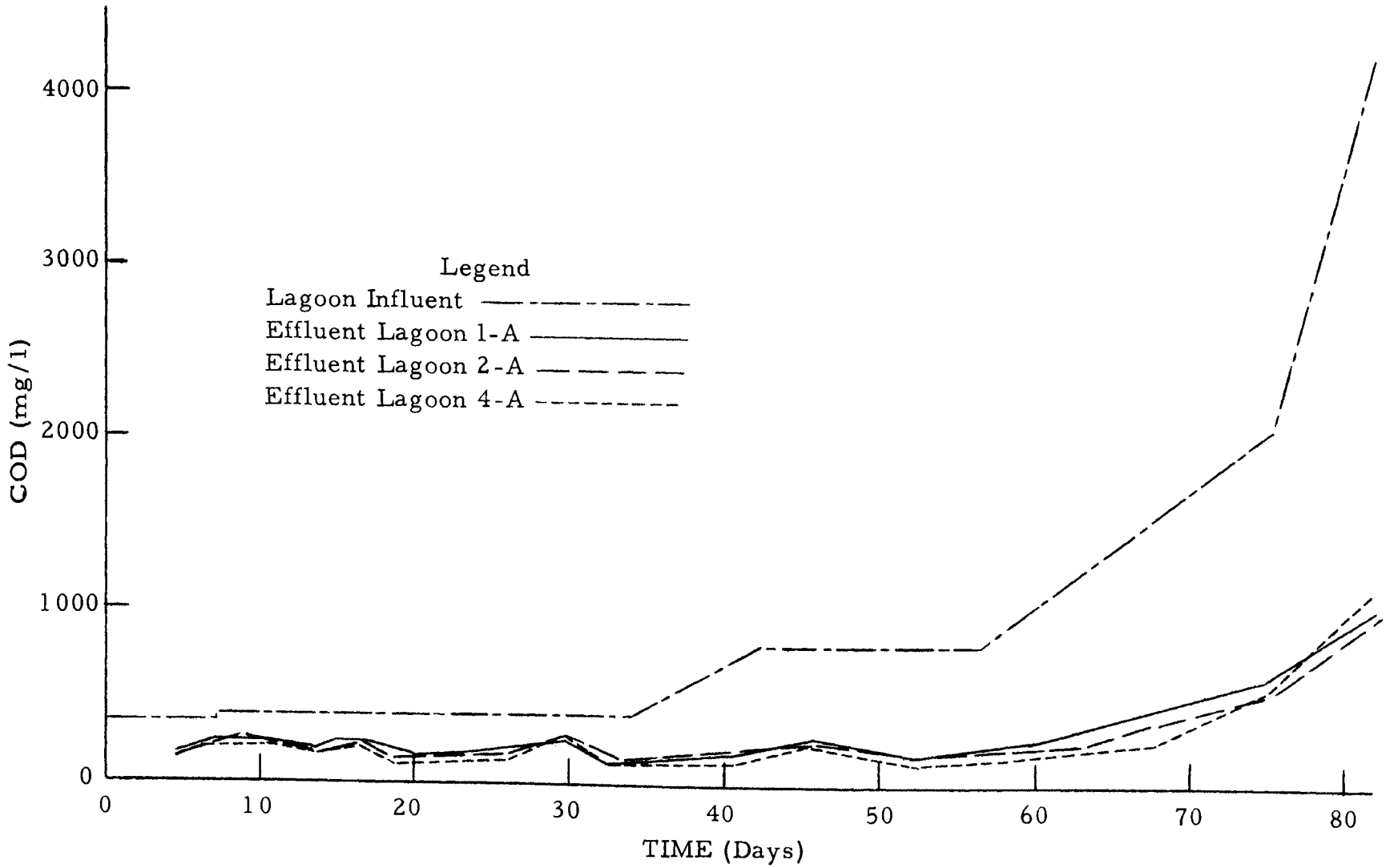


Figure 4. A Comparison of the Influent and Effluent COD of Lagoons 1-A, 2-A, and 4-A.

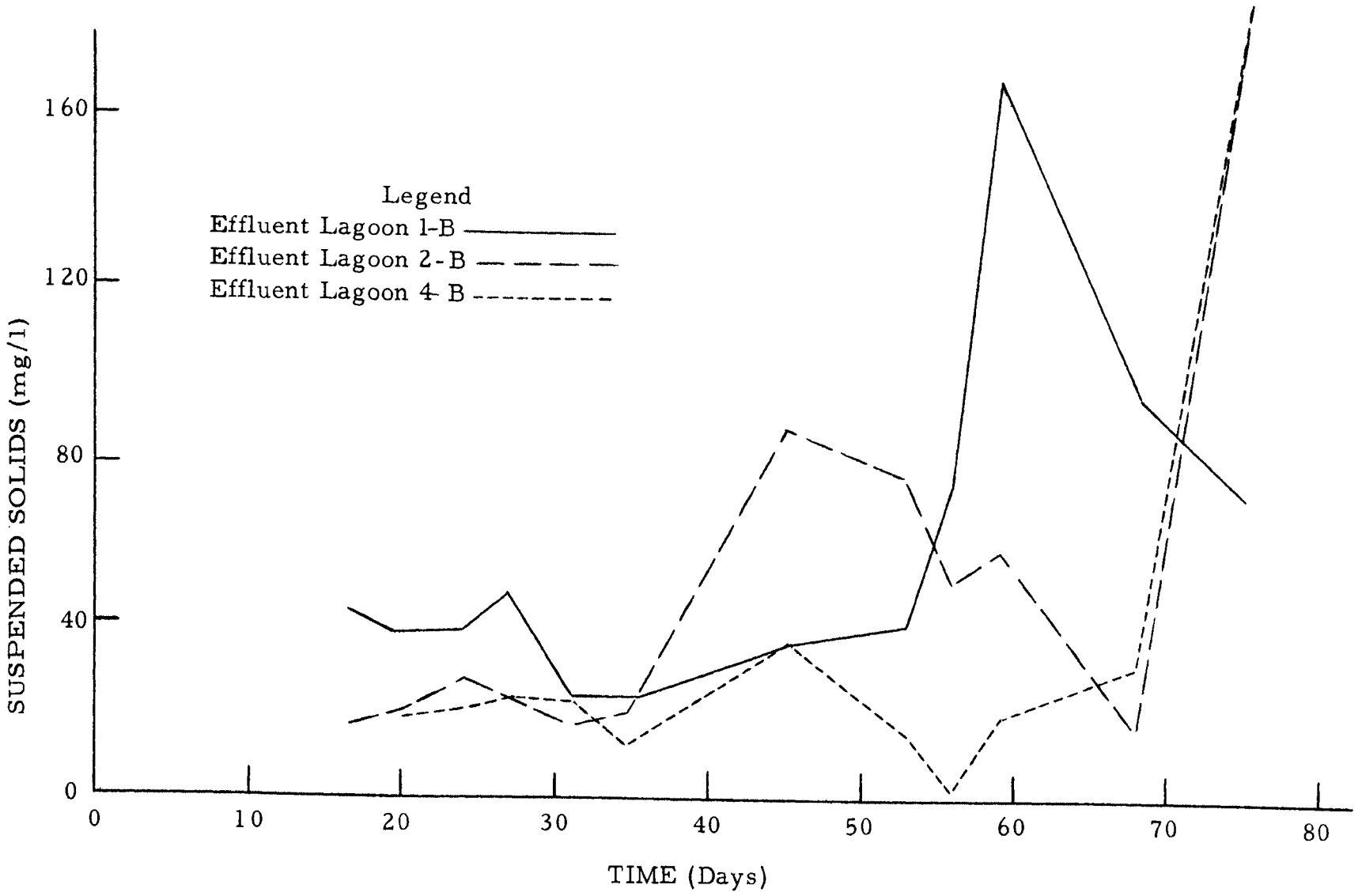


Figure 5. A Comparison of the Suspended Solids in the Effluents of Lagoons 1-B, 2-B, and 4-B.

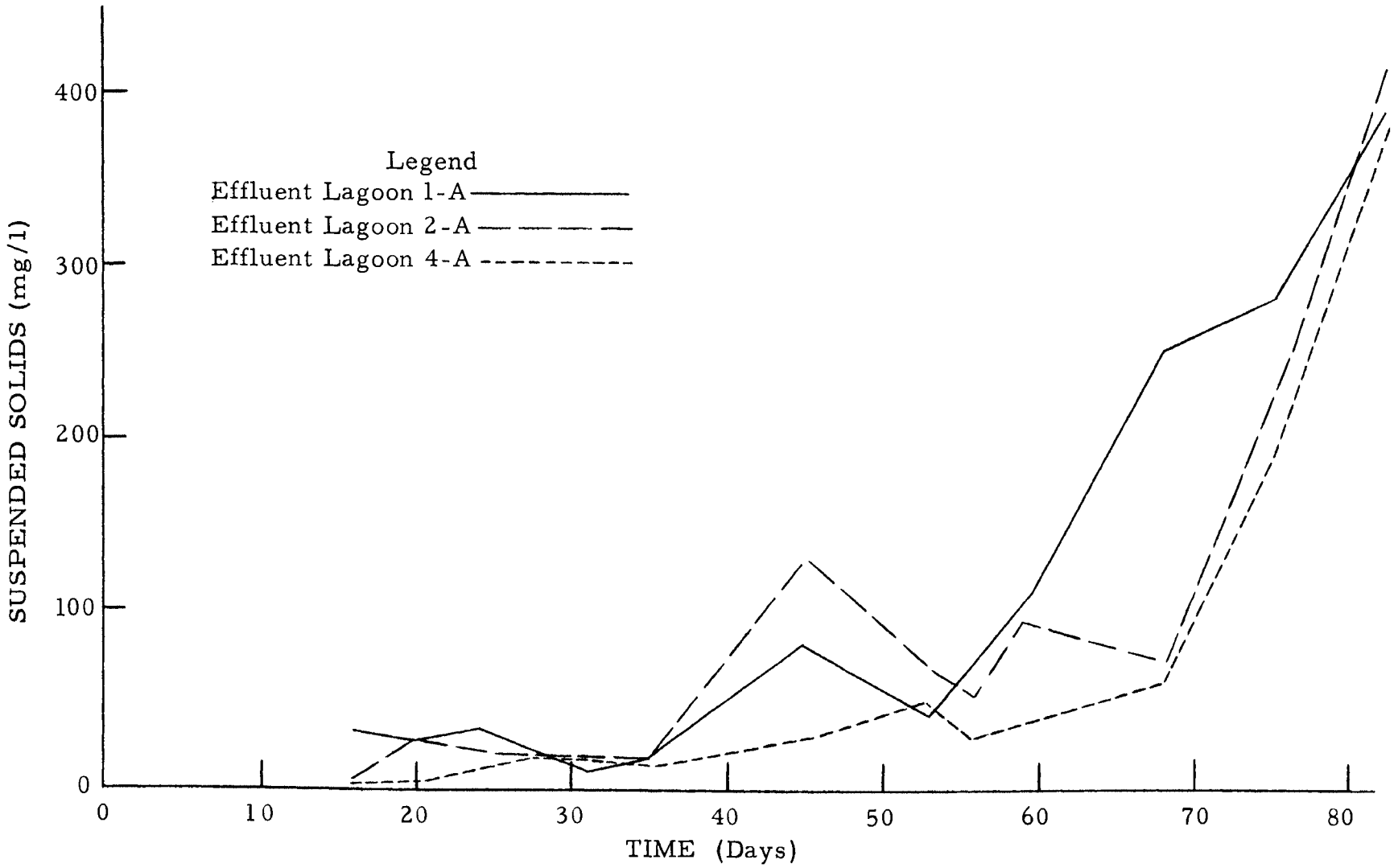


Figure 6. A Comparison of the Suspended Solids in the Effluents of Lagoons 1-A, 2-A, and 4-A.

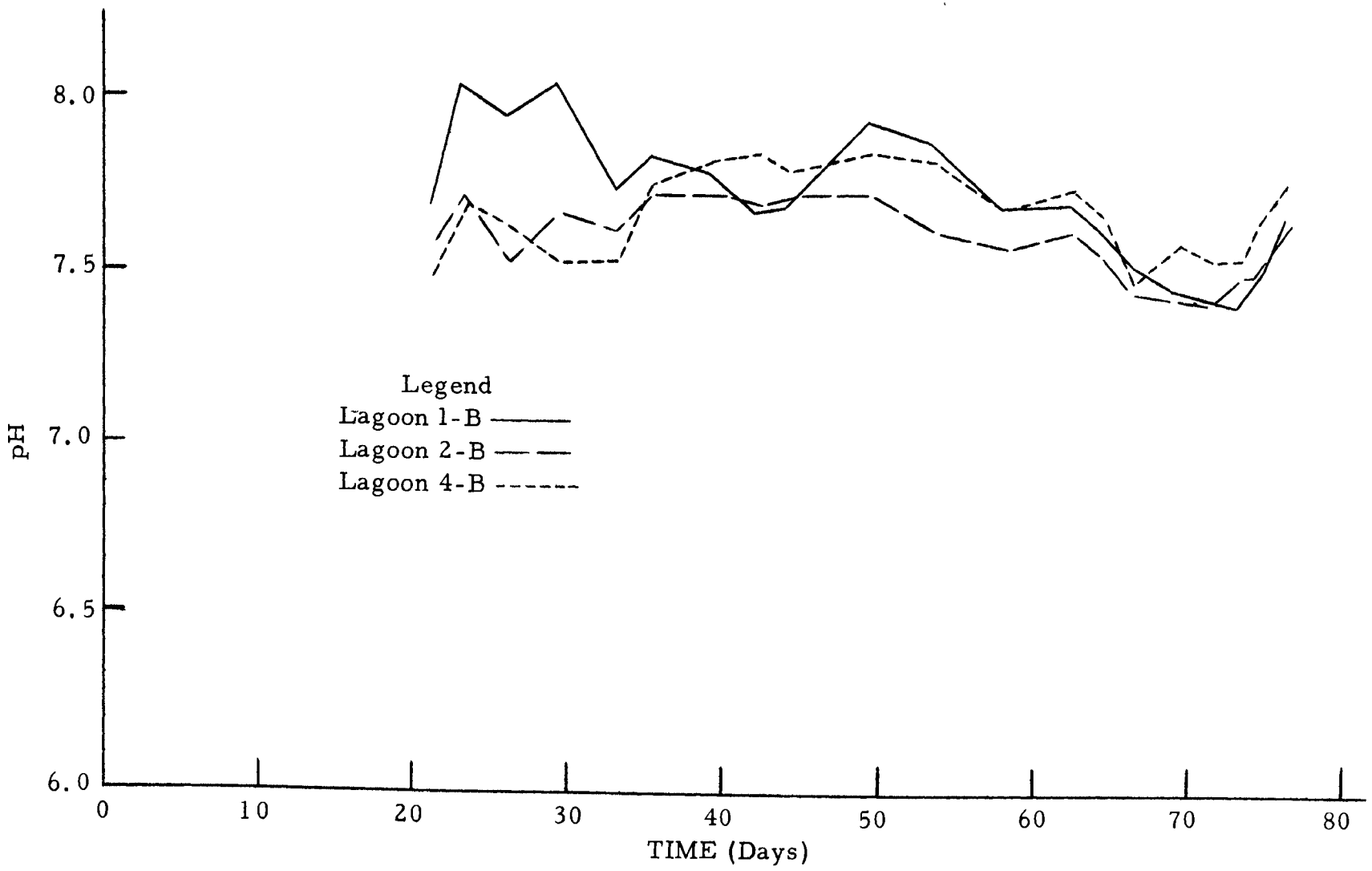


Figure 7. A Comparison of the pH of Lagoons 1-B, 2-B, and 4-B.

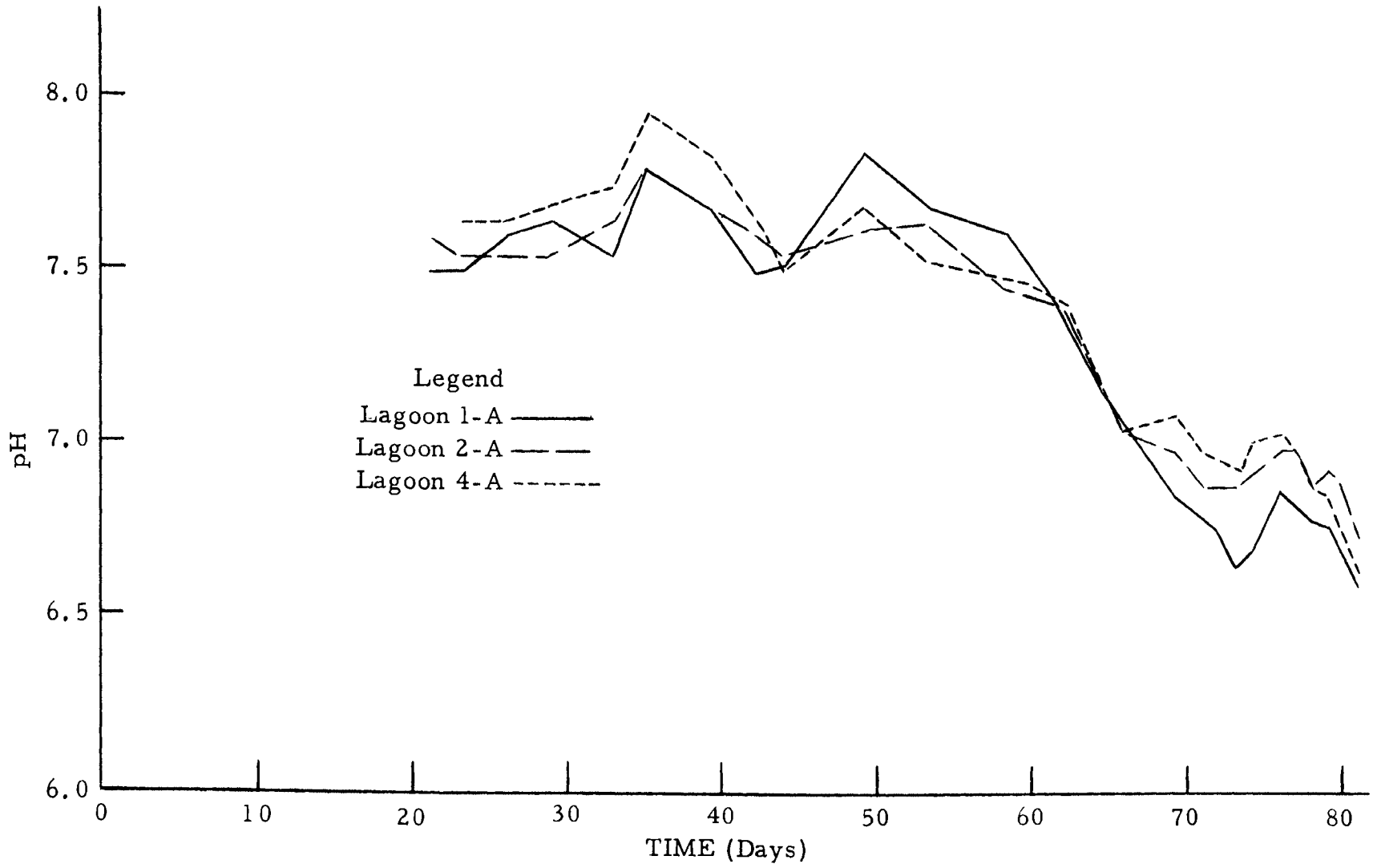


Figure 8. A Comparison of the pH of Lagoons 1-A, 2-A, and 4-A.

water was always zero or very nearly zero. No discernible differences in the dissolved oxygen content of the various lagoons were detected. The results of the dissolved oxygen determinations were verified with a dissolved oxygen probe. After approximately three weeks of operation, diurnal dissolved oxygen concentration was determined. Samples were taken every three hours beginning at 6:00 a.m. Determinations throughout the day indicated a zero dissolved oxygen content in all of the lagoons, therefore, samples were not continued through the hours of darkness. The results of the dissolved oxygen determinations are presented in Appendix A.

BOD determinations were run on the effluent from each lagoon after approximately eight weeks of operation. The results of these tests indicated a BOD to COD ratio of not less than 70 per cent. The results of the BOD determinations are presented in Appendix A.

After approximately five weeks of operation alkalinity determinations were performed on the effluent from each lagoon. The results from all lagoons indicated an effluent alkalinity of approximately 300 mg/l total alkalinity measured as calcium carbonate.

Periodic microscopic examination of the contents of each lagoon indicated the presence of an unsteady microbial population. The microbial population was made up primarily of highly motile organisms indicating that the system existed in a high energy and continually changing state (10). This observation is further supported by the operational data presented in Figures 3 through 6. The domination of

any single type of organism never lasted more than a few days at a time. This was evidenced dramatically in lagoon 4-B after approximately eight weeks of operation. At this time rotifers almost completely dominated the lagoon overnight. The presence of this organism was accompanied by a very clarified effluent low in COD and suspended solids. The domination of this specific organism lasted for approximately one week and then gave way to a lower form of life. Various types of algae were always present in the lagoons.

Visual examination of the lagoons indicated the development of a very dense microbial growth occurring on the panels. After approximately two weeks of operation the growth appeared along the top portion of the panels and proceeded to cover the entire panel. The growth was initially light green in color but eventually turned very dark. After approximately seven weeks of operation, the growth on the panels began to undergo continual sloughing. The sloughing was always followed by an immediate regrowth of organisms. Figure 9 illustrates the density of the growth which occurred on the solid-liquid interface in the lagoons. This picture was taken after the investigation had been completed and the lagoons were drained. Figure 10 is a microscopic photograph of the growth which occurred on the solid-liquid interface in the lagoons. The glass slide from which this picture was taken was immersed in one of the lagoons until a dense growth appeared, then removed, and examined.

These results were obtained over a period of approximately 11

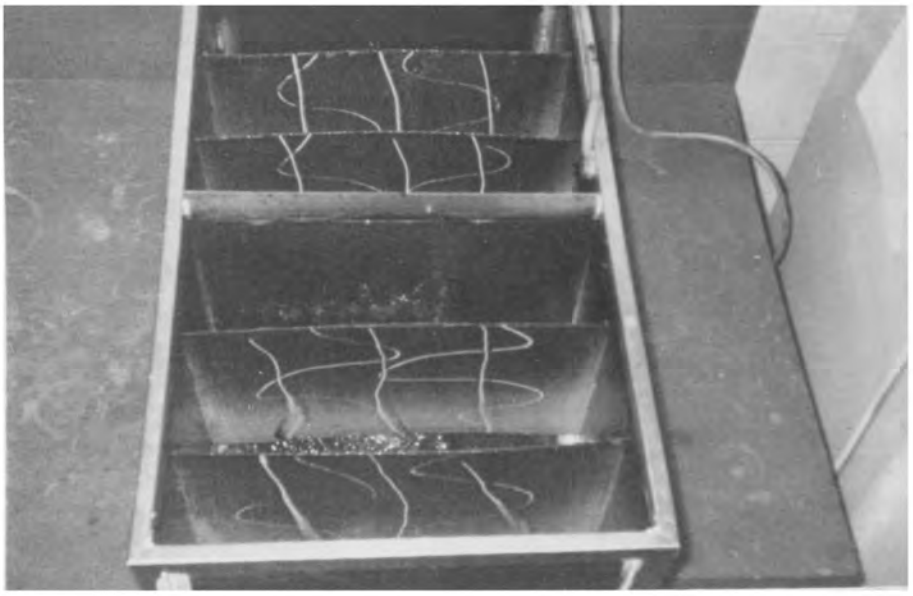


Figure 9. The Density of the Growth which Occurred on the Solid-Liquid Interface.

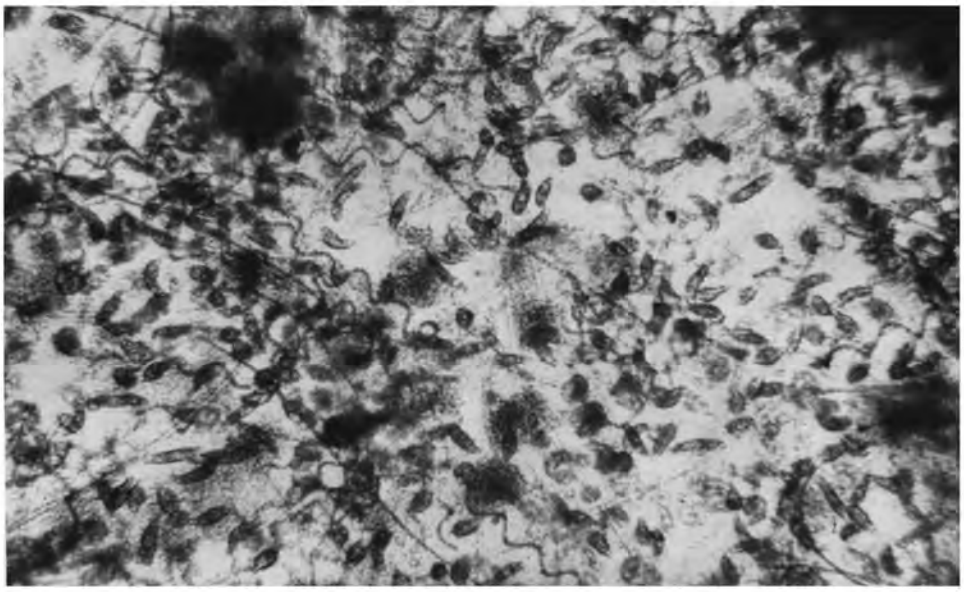


Figure 10. A Microscopic Close-up (100 x) of the Growth which Occurred on the Solid-Liquid Interface.

weeks of operation. The analyses did not follow a specific time schedule but were run on a periodic basis.

# V. DISCUSSION OF RESULTS

According to the results obtained from this investigation, little improvement in the performance was observed when the solid-liquid interfacial area in the laboratory lagoons was increased. During certain periods of operation there were noticeable differences in the characteristics of the effluent, as seen from Figures 3 through 8. These differences did not prevail for enough time to indicate specific trends in the characteristics of the effluents.

The quality of the effluent from each lagoon varied throughout the entire time of operation to some extent. This variation seemed to form an oscillatory pattern while the lagoons were being fed an influent of constant strength. Although this pattern of operation indicates somewhat unstable conditions in the lagoons, it is typical of lagoon operation. Steady state operation would be very difficult to achieve in the laboratory due to the small size of the lagoons. Since all lagoons in each set were operated under the same conditions and exhibited similar characteristics, the absence of a high degree of stability in the lagoons should not affect the outcome of this investigation. Any variations which occurred appeared to be similar for all the lagoons.

It was expected that an increase in the solid-liquid interfacial area would promote an increase of the microbial population. This increased population would then be capable of stabilizing a greater

organic loading placed on the lagoons. However, results of this investigation indicate that the addition of the panels did not improve the stabilization characteristics of the laboratory lagoons. In fact, all of the lagoons seemed to exhibit similar stabilization characteristics. This would imply that there was little difference in the active microbial populations present in each lagoon. Since the lagoons with the added panels did have the capability and did in fact support a greater microbial population in the attached state, some factor had to be limiting the growth and activity of the organisms. It is apparent from the results obtained that the dissolved oxygen content of the lagoon media could be a limiting factor.

After a short period of operation the dissolved oxygen content in all the lagoons dropped to zero. The lack of dissolved oxygen would prevent further growth of any strictly aerobic forms.

A zero dissolved oxygen content is not commonly found in the operation of field lagoons where moderate loading rates are being applied except in the benthic zone. This is true especially during daylight hours when algal photosynthesis is producing oxygen. There was no dissolved oxygen present in the laboratory lagoons during any period of the day even though relatively low loading rates were being used (57.6 pounds of COD per acre per day). There was a greater amount of oxygen depletion in the laboratory lagoons as compared to field lagoons, possibly due to the presence of a larger microbial population. If a greater microbial population were present in the

laboratory lagoons, they would utilize more oxygen and effectively remove it as rapidly as it became available. It should be pointed out that a zero dissolved oxygen content is not uncommon to laboratory lagoon operations (7).

It is recognized that other factors could affect the amount of dissolved oxygen present in a laboratory lagoon as compared to a field lagoon. Differences in the rates of atmospheric reaeration could be responsible for the lack of dissolved oxygen in the laboratory lagoons. However, it has been pointed out by other investigators that atmospheric reaeration contributes only a negligible amount of oxygen to the liquid in the lagoon operation (11).

Anaerobic and facultative anaerobic activity play an important role in the stabilization process carried out in a field lagoon, therefore, the contribution of these types of microbial activity in the laboratory lagoons should be evaluated. Due to the shallowness of the laboratory lagoons, the effects of a benthal region could not be evaluated since a community of strictly anaerobic organisms would not be favored. However, it is apparent that facultative anaerobic organisms were present as evidenced by the zero dissolved oxygen content. The aerobic activity of the organisms in the laboratory lagoons was limited by the lack of oxygen, and the anaerobic activity was limited by the lack of substrate (12). If the microbial activity was indeed limited by these factors, little differences could be expected in the stabilization characteristics of the lagoons.

If one examines the solid-liquid interfacial area to volume ratio of a field lagoon as compared to a laboratory lagoon, it is apparent that laboratory lagoons are capable of supporting a greater microbial population in the attached state. The SLIA to volume ratio of a relatively small field lagoon one acre in area with a liquid depth of 3 ft would be approximately 0.33 $ft^2/ft^3$. The aquariums which were used in this investigation had a SLIA to volume ratio of approximately 4 $ft^2/ft^3$ before any additional SLIA was added. This comparison shows that the laboratory lagoons had a SLIA to volume ratio twelve times greater than that of full-scale field lagoons. It is therefore possible for a greater attached microbial population to develop in a laboratory lagoon even without the bio-growth panels, as compared to an equal volume in a field lagoon.

If a more dense microbial population does develop in a laboratory lagoon as compared to a field lagoon, this would explain why the dissolved oxygen content in the laboratory lagoons was zero. The increased microbial population was utilizing the oxygen as fast as it was being put into the system. This would further explain why similar stabilization characteristics were exhibited by all of the laboratory lagoons. All of the lagoons had essentially the same active microbial population since all growth was limited by the same factors. Even the laboratory lagoons with the least amount of SLIA were capable of producing enough microbial life to limit the activity of the system. The addition of further SLIA would have little effect on the active

microbial population, and therefore, little effect on the stabilization characteristics.

If the laboratory lagoons will indeed produce a denser microbial population than field lagoons because of their greater SLIA to volume ratio, it would be expected that the stabilization capabilities of laboratory lagoons would be superior to that of field lagoons. An investigation of the literature reveals that this is indeed the case (7,11).

In view of what has been said, it is felt that the addition of SLIA to a field wastewater lagoon could increase the microbial population and the stabilization potential of the lagoon. Since the optimum SLIA to volume ratio appears to exist somewhere between that found in field and laboratory lagoons, further investigations on field lagoons are needed to fully evaluate the potential involved.

# VI. CONCLUSIONS

The following conclusions were reached as a result of this investigation.

1. Design characteristics for field lagoons cannot be obtained from investigations on laboratory lagoons, due to the difference in their respective SLIA to volume ratios.
2. A substantial microbial growth will develop on added SLIA in a laboratory wastewater stabilization lagoon.
3. The addition of SLIA to laboratory lagoons has little effect on their stabilization characteristics.

# VII. FURTHER RESEARCH NEEDS

To fully evaluate the possible potential of improving the treatment capabilities of a lagoon by the addition of SLIA, investigations must be conducted on full-scale field lagoons. The SLIA to volume ratio found in a laboratory lagoon is so high that further addition of SLIA has little effect on its treatment capabilities.

Since a dense microbial growth will develop on added SLIA in a lagoon, investigations should be conducted to determine the feasibility of harvesting the growth from the panels. This would reduce the nutrient load on the receiving stream and provide a source of high protein material which might be used for the feeding of domestic animals.

# BIBLIOGRAPHY


1. Canter, Larry W., Englande, Andrew J., and Mauldin, Alfred F., "Loading Rates on Waste Stabilization Ponds", Journal of the Sanitary Engineering Division, ASCE, Vol 95, No SA6, 1117-1128, 1969.

2. Klock, John W., and Durham, Howard V., "Wastewater Lagoon Modifications", Journal Water Pollution Control Federation, Vol 39, No 5, 835-845, 1967.

3. Nemerow, Nelson L., "Accelerated Waste Water Oxidation Pond Pilot Plant Studies", Advances in Biological Waste Treatment, W. Eckenfelder and J. McCabe Editors, 395-397, Pergamon Press, Oxford , 1964.

4. Antonie, Ronald L., "Response of the Bio-Disc Process to Fluctuating Wastewater Flows", Proceedings of the 25th Industrial Waste Conference, Purdue University, 1970.

5. Kato, K., and Yasuhiro, S., "Fixed Activated Sludge Process for Industrial Waste Treatment", Proceedings of the 22nd Industrial Waste Conference, Purdue University, 1967.

6. Eckenfelder, W. W., and O'Connor, D. J., "Biological Waste Treatment", Pergamon Press, Oxford, 1961.

7. Hermann, E. R., and Gloyna, E.F., "Waste Stabilization Ponds", Sewage and Industrial Wastes, Vol 30, No 4, 511-538, 1958.

8. Personal Communication with Mrs. Mary E. Taylor of Carnation Company Research Laboratories, Letter Dated September 29, 1970.

9. Anonymous, Standard Methods for the Examination of Water and Wastewater, 12 Ed., New York, American Public Health Association, 1965.

10. McKinney, Ross E., "Microbiology for Sanitary Engineers", McGraw-Hill, New York, 1962.

11. Mills, Donald A., "Depth and Loading Rates for Oxidation Ponds", Water and Sewage Works, Vol 108, No 9, 343-346, 1961.

12. Parker, C. D., Jones, H. L., and Taylor, W. S., "Purification of Sewage in Lagoons", Sewage and Industrial Wastes, Vol 22, No 6, 760-775, 1950.

# VITA

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He received his primary and secondary education in Dexter, Missouri. He has received his college education from the University of Missouri - Rolla, in Rolla, Missouri. He received a Bachelor of Science degree in Civil Engineering from the University of Missouri - Rolla, in Rolla, Missouri, in May 1967.

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# APPENDIX A

## EXPERIMENTAL RESULTS

The experimental results obtained in this investigation are presented in Tables A-I through A-VII. The column heading in each table which reads "time in days", refers to the number of days the lagoons had been in operation when the results were determined.

Table A - I. Results of COD Analyses.

| TIME IN DAYS | EFFLUENT COD (mg/l) | | | | | |
|---|---|---|---|---|---|---|
| | 1-A | 2-A | 4-A | 1-B | 2-B | 4-B |
| 3 | 356 | 352 | 324 | 400 | 380 | 340 |
| 5 | 192 | 154 | 169 | 177 | 131 | 146 |
| 7 | 244 | 228 | 236 | 206 | 228 | 251 |
| 9 | 244 | 260 | 244 | 221 | 244 | 267 |
| 11 | 238 | 184 | 192 | 207 | 192 | 184 |
| 13 | 180 | 150 | 150 | 180 | 150 | 150 |
| 15 | 256 | 184 | 200 | 224 | 160 | 200 |
| 17 | 232 | 208 | 185 | 208 | 178 | 201 |
| 19 | 169 | 123 | 100 | 123 | 123 | 123 |
| 23 | 162 | 147 | 116 | 139 | 154 | 116 |
| 26 | 196 | 160 | 138 | 146 | 131 | 153 |
| 30 | 246 | 284 | 284 | 300 | 270 | 292 |
| 33 | 109 | 116 | 109 | 116 | 101 | 109 |
| 43 | 203 | 226 | 173 | 158 | 173 | 150 |
| 46 | 269 | 269 | 238 | 231 | 216 | 179 |
| 52 | 165 | 173 | 133 | 141 | 141 | 118 |
| 55 | 195 | 188 | 148 | 164 | 156 | 102 |
| 60 | 277 | 232 | 187 | 210 | 172 | 105 |
| 64 | 358 | 261 | 246 | 261 | 164 | 119 |
| 68 | 455 | 384 | 266 | 227 | 110 | 118 |
| 75 | 623 | 515 | 561 | 208 | 115 | 131 |
| 82 | 1040 | 982 | 1200 | | | |

Table A-II. Loading Schedule for Lagoons in Set A.

| TIME IN DAYS | INFLUENT COD (mg/l) | LOADING RATE (lb/COD/acre/day) |
|---|---|---|
| 1 | 355 | 51.1 |
| . | . | . |
| . | . | . |
| . | . | . |
| 7 | 400 | 57.6 |
| . | . | . |
| . | . | . |
| . | . | . |
| 35 | 450 | 64.8 |
| 36 | 500 | 72.0 |
| 37 | 550 | 79.2 |
| 38 | 600 | 86.4 |
| 39 | 650 | 93.6 |
| 40 | 700 | 100.8 |
| 41 | 750 | 108.0 |
| 42 | 800 | 115.2 |
| . | . | . |
| . | . | . |
| . | . | . |
| 57 | 853 | 122.9 |
| 58 | 921 | 132.7 |
| 59 | 990 | 142.6 |
| 60 | 1058 | 152.4 |
| 61 | 1126 | 162.2 |
| 62 | 1194 | 172.1 |
| 63 | 1263 | 181.9 |
| 64 | 1331 | 191.7 |
| 65 | 1400 | 201.5 |
| 66 | 1468 | 211.4 |
| 67 | 1537 | 221.2 |
| 68 | 1605 | 231.0 |
| 69 | 1673 | 240.9 |
| 70 | 1741 | 250.7 |
| 71 | 1810 | 260.5 |
| 72 | 1878 | 270.3 |
| 73 | 1947 | 280.2 |
| 74 | 2015 | 290.0 |
| 75 | 2084 | 299.9 |
| 76 | 2425 | 349.1 |
| 77 | 2767 | 398.2 |
| 78 | 3108 | 447.4 |
| 79 | 3450 | 496.5 |
| 80 | 3792 | 545.6 |
| 81 | 4133 | 594.8 |

Table A -III. Loading Schedule for Lagoons in Set B.

| TIME IN DAYS | INFLUENT COD (mg/l) | LOADING RATE (lb/COD/acre/day) |
|---|---|---|
| 1 | 355 | 51.1 |
| . | . | . |
| . | . | . |
| . | . | . |
| 7 | 400 | 57.6 |
| . | . | . |
| . | . | . |
| . | . | . |
| 75 | 400 | 57.6 |

Table A-IV. Results of Suspended Solids Analyses.

| TIME IN DAYS | SUSPENDED SOLIDS (mg/l) | | | | | |
|---|---|---|---|---|---|---|
| | 1-A | 2-A | 4-A | 1-B | 2-B | 4-B |
| 16 | 34 | 6 | 2 | 46 | 16 | -- |
| 20 | 28 | 29 | 4 | 39 | 21 | 19 |
| 24 | 35 | 21 | 13 | 40 | 28 | 21 |
| 27 | 24 | 20 | 21 | 48 | 24 | 24 |
| 31 | 12 | 20 | 16 | 25 | 17 | 23 |
| 35 | 16 | 17 | 13 | 24 | 21 | 13 |
| 45 | 86 | 136 | 32 | 38 | 88 | 38 |
| 53 | 44 | 74 | 54 | 42 | 76 | 16 |
| 56 | 78 | 56 | 32 | 78 | 52 | 2 |
| 59 | 110 | 100 | 66 | 170 | 60 | 20 |
| 68 | 256 | 76 | 64 | 96 | 16 | 32 |
| 75 | 288 | 232 | 196 | 72 | 184 | 184 |
| 82 | 400 | 420 | 384 | | | |

Table A-V. Results of pH Analyses.

| TIME IN DAYS | AVERAGE pH VALUES | | | | | |
|---|---|---|---|---|---|---|
| | 1-A | 2-A | 4-A | 1-B | 2-B | 4-B |
| 21 | 7.5 | 7.6 | 7.6 | 7.7 | 7.6 | 7.5 |
| 23 | 7.5 | 7.5 | 7.6 | 8.0 | 7.7 | 7.7 |
| 26 | 7.6 | 7.5 | 7.6 | 7.9 | 7.5 | 7.6 |
| 29 | 7.6 | 7.5 | 7.7 | 8.0 | 7.7 | 7.5 |
| 33 | 7.5 | 7.6 | 7.7 | 7.7 | 7.6 | 7.5 |
| 35 | 7.8 | 7.8 | 7.9 | 7.8 | 7.7 | 7.7 |
| 39 | 7.7 | 7.7 | 7.8 | 7.8 | 7.7 | 7.8 |
| 42 | 7.5 | 7.6 | 7.6 | 7.7 | 7.7 | 7.9 |
| 44 | 7.5 | 7.5 | 7.5 | 7.7 | 7.7 | 7.8 |
| 49 | 7.8 | 7.6 | 7.7 | 7.9 | 7.7 | 7.9 |
| 53 | 7.7 | 7.6 | 7.5 | 7.9 | 7.6 | 7.8 |
| 58 | 7.6 | 7.5 | 7.5 | 7.7 | 7.6 | 7.7 |
| 62 | 7.4 | 7.4 | 7.4 | 7.7 | 7.6 | 7.8 |
| 64 | 7.2 | 7.2 | 7.2 | 7.6 | 7.6 | 7.7 |
| 66 | 7.1 | 7.0 | 7.0 | 7.5 | 7.5 | 7.5 |
| 69 | 6.9 | 7.0 | 7.1 | 7.5 | 7.4 | 7.6 |
| 71 | 6.8 | 6.9 | 7.0 | 7.4 | 7.4 | 7.6 |
| 73 | 6.6 | 6.9 | 6.9 | 7.4 | 7.5 | 7.6 |
| 74 | 6.7 | 6.9 | 7.0 | 7.5 | 7.5 | 7.7 |
| 76 | 6.9 | 7.0 | 7.0 | 7.7 | 7.6 | 7.8 |
| 77 | 6.8 | 7.0 | 7.0 | | | |
| 78 | 6.8 | 6.9 | 6.9 | | | |
| 79 | 6.8 | 6.9 | 6.9 | | | |
| 80 | 6.7 | 6.9 | 6.7 | | | |
| 81 | 6.6 | 6.7 | 6.6 | | | |

Table A-VI. Results of Dissolved Oxygen Analyses.

| TIME IN DAYS | TIME OF DAY | DISSOLVED OXYGEN CONTENT (mg/l) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1-A | 2-A | 4-A | 1-B | 2-B | 4-B |
| 10 | 9 am | 0.7 | 0 | 0.1 | 0 | 0.5 | 0.6 |
| 12 | 9 am | 1.5 | 0.1 | 0 | 0 | 0 | 0 |
| 14 | 9 am | 0 | 0 | 0 | 0 | 0 | 0 |
| 21 | 6 am | 0 | 0 | 0 | 0 | 0 | 0 |
| 21 | 9 am | 0 | 0 | 0 | 0 | 0 | 0 |
| 21 | 12 noon | 0 | 0 | 0 | 0 | 0 | 0 |
| 21 | 3 pm | 0 | 0 | 0 | 0 | 0 | 0 |
| 21 | 6 pm | 0 | 0 | 0 | 0 | 0 | 0 |
| 23 | 1 pm | 0 | 0 | 0 | 0 | 0 | 0 |
| 33 | 12 noon | 0 | 0 | 0 | 0 | 0 | 0 |
| 42 | 2 pm | 0 | 0 | 0 | 0 | 0 | 0 |

Table A-VII. Results of BOD Analyses.

| LAGOON | BOD (mg/l) | BOD/COD (percent) |
|---|---|---|
| 1-A | 140 | 85 |
| 2-A | 123 | 71 |
| 4-A | 123 | 93 |
| 1-B | 123 | 87 |
| 2-B | 104 | 74 |
| 4-B | 104 | 89 |